numbers thus far issued. In the first number the editor comments on some of the open questions, and in the second, as bearing on the relations of neurology to psychology, gives an historical account of the ideas on localization of function in the brain.

Running through both numbers is a laborious study of the avian brain by C. H. Turner, in which, for one thing, he tests the taxonomic value of the brain of birds, with suggestive results. In the first number the editor writes on "Illustrations of the Architecture of the Cerebellum." Under this head he presents the view that the superficial layer of the cerebellar cortex—the molecular layer—is, in part at least, derived from cells forming the walls of the recessus lateralis—a view which certainly requires more evidence to support it than is here given.

The remaining papers, three in number, are studies in comparative anatomy.

A LABORATORY COURSE IN PHYSIOLOGICAL PSYCHOLOGY.

BY EDMUND C. SANFORD, PH. D.

(*Second Paper.*)

III.—TASTE AND SMELL.

SENSATIONS OF TASTE.

Apparatus. A potato and an apple; standard solutions of sweet, bitter, sour and salt; camel's-hair brushes; battery and zinc electrodes. The standard solutions should be made of two strengths, the stronger for testing the individual papillæ and the weaker for finding the least proportion tastable. The following proportions of tastable substances and water are convenient. Stronger solutions: Sugar, 40:100; Quinine, 2:100; Tartaric Acid, 5:100; Salt, saturated solution. Weaker solutions, (for which the water itself should be without taste): Sugar, 5:100; Quinine, 2:100 000; Tartaric Acid, 5:1000; Salt, 2:100. Special solutions of Sugar for Ex. 52: 20:100, 18:100, 16:100, 14:100, 12:100, 10:100.

49. Much of what is commonly called taste is really taste plus smell or touch or both. With the eyes shut and the nostrils held try to distinguish, by taste alone, between small quantities of scraped apple and potato, placed upon the tongue.

50. Distribution of the Organs of Taste. *a.* Using the weaker solutions and operating with a mirror or on another person, find out as nearly as you can in what part of the tongue the strongest sensations are produced by each. Test the tip, the sides, the back and the middle, putting on the solutions with a camel's-hair brush and rinsing the mouth as often as necessary. Try also the hard and soft palates. *b.* Dry the tongue with a handkerchief and test the individual fungiform papillæ with the stronger solutions, applying them with fine camel's-hair pencils. It will be found possible to get taste sensations from the single papillæ, though perhaps not all four from each. Rinse the mouth as needed. *c.* Test the surface of the tongue between the papillæ and observe that no taste sensations follow.

On *a* cf. Rittmeyer: Geschmacksprüfungen, Göttingen Diss. 1885. On *b* and *c* cf. Oehrwall, Untersuchungen über den Geschmackssinn, Scandinav. Archiv f. Physiol. Bd. II, 1890, pp. 1-69; see also abstract by the author in the Zeitschrift f. Psych., Bd. I, 1890, p. 141.

51. Minimal tastes. *a.* Find what is the greatest dilution of the weaker solutions in which the characteristic tastes can still be recognized. The same quantity, *e. g.*, half a teaspoonful, should be taken into the mouth at each trial and may be swallowed with advantage. Rinse

the mouth thoroughly as required. The following are the proportions given by Bailey and Nichols for male observers: Quinine, 1:390 000; Sugar, 1:199; Salt, 1:2240; for Sulphuric Acid, which they used instead of Tartaric, the proportion was 1:2080. *b*. The intensity of the sensation and the greatest dilution still tastable depend on the number of taste organs stimulated. Take a portion of one of the solutions of just tastable strength found in *a*, add an equal quantity of water and take a large mouthful of the mixture. The characteristic taste will still be perceived, perhaps more strongly than before.

On *a* cf. Bailey and Nichols, The Delicacy of the Sense of Taste, Nature, XXXVII, 1887-88, 557; and Lombroso und Ottolenghi, Die Sinne der Verbrecher, Zeitschrift für Psychologie Bd. II, 1891, pp. 346-48. Camerer, Die Grenzen der Schmeckbarkeit von Chlornatrium in wässriger Lösung, Pflüger's Archiv, II, 1869, 322. On *b* cf. Camerer, Die Methode der richtigen und falschen Fälle angewendet auf den Geschmackssinn. Zeitschrift für Biologie, XXI, 570.

52. Discriminative sensibility for taste. For a rough determination test with the solutions of sugar indicated above, taking first a small quantity of the standard 20% solution, then an equal quantity (the equality is important) of one of the weaker solutions, or first one of the weaker and then the standard, until a solution is found that is just recognizably different from the standard. Make this determination several times. The excess of sugar in the standard solution over the amount in the solution just observably weaker set in a ratio to the total percentage of sugar in the standard measures the sensibility. Some experimenters may be able to distinguish the 18% from the 20% solution; their sensibility would then be expressed by the ratio 2:20.

On such experiments as this cf. Keppler, Das Unterscheidungsvermögen des Geschmacksinnes für Concentrationsdifferenzen der schmeckbaren Körper. Pflüger's Archiv, II, 1869, 449.

53. Electrical Stimulation. *a*. Using a constant current and two zinc electrodes one above, the other under the tongue notice the sour taste at the positive pole and the alkaline at the negative.

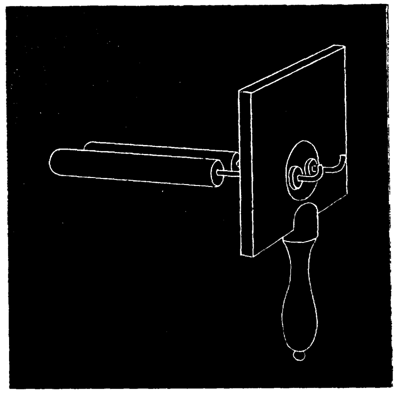
On the sensations of taste in general cf. von Vintschgau, Physiologie des Geschmackssinne, Hermann's Handbuch der Physiologie, III, (pt. 2) pp. 145-224; Oehrwall, *op. cit.* On acid tastes and chemical composition cf. Corin, Action des acides sur le goût, Archives de Biologie, VIII, fasc. 1.

SENSATIONS OF SMELL.

Apparatus. Essence of cloves; olfactometer of Zwaardemaker; camphor gum; yellow wax; a dozen small wide mouthed bottles. The essence of cloves is made by adding one part of oil of cloves to fifteen parts of alcohol[1] and may be diluted with water, itself odorless, to make the solutions required in Ex. 54. For that experiment dilutions of the essence that will give the following proportions of oil of cloves will be found convenient: 1:50 000; 1:100 000; 1:200 000; 1:300 000; 1:400 000; 1:500 000. The olfactometer of Zwaardemaker in simple clinical form may be bought of Mechaniker Harting Bank, Utrecht, at 1.50 mk.; but

[1] Whether this essence is of the same strength as that used by Lombroso and Ottolenghi in their experiments to which reference is made below, the writer does not know.

its construction is so simple that it may easily be made in the laboratory. It will be most convenient if made double as shown in the accompanying cut. The instrument consists of a light wooden screen, say six inches square, provided with a handle below for easier holding. Through this screen, a little below the middle, a hole an inch and a half in diameter is bored, and fitted with a large cork. The cork in turn is pierced with two holes side by side an inch apart and of such size as to fit tightly upon the glass tubes next to be mentioned i. e. about 7 mm. The glass tubes should be long enough to leave 10 cm. free behind the screen and about 3 cm. free in front. The front ends are bent upward at right angles for insertion in the nostrils.



The odorous substances used in this instrument are applied in the form of tubes that slide over the glass tubes behind the screen. The simplest and best for persons of normal keenness of smell are pieces of red rubber tubing 10 cm. long and of such bore as just to slide freely over the glass tubes (8 mm.). These pieces of rubber tubing should themselves be slipped into pieces of tight fitting glass tubing so as to prevent the spread of the odor from their outer surface. For Ex. 57 another odor tube, this time of yellow wax will be needed. This can easily be made by placing a glass tube (of the size of the air tubes used in the olfactometer) inside a tube such as is used to cover the rubber odor-tubes and filling the space between them with melted wax. The inner tube may then be warmed by running hot water through it till it can be withdrawn. The principle upon which the instrument works is this, namely, that the intensity of the odor varies directly as the surface of odorous substance exposed. When the odor-tubes are slipped onto the glass tubes of the olfactometer and pushed back until their ends are flush with those of the glass tubes, the air inhaled through the latter contains few or no odorous particles because no odorous surface is exposed. When, however, the odor-tubes are pulled a little away from the screen so that they extend over the ends of the glass tubes, they expose the odorous surface inside them to the current of air inhaled. The strength of the odor is proportional to the area exposed, or since the bore does not change, to the length of odor tube that extends beyond the glass tube. This last can be conveniently measured by a scale (*e. g.* centimeters and half centimeters) scratched on the inner glass tubes. The length of odor tube corresponding to a just observable odor will, of course, differ with different tubes, from person to person, and with the temperature, but tubes of red rubber are reported to give satisfactory results both as to original intensity and the constancy with which they keep their odor through considerable periods of time. The length of red rubber odor tube required by Zwaardemaker himself for a just observable odor at 18° C. is 7 mm. In use the upward turned end of one of the glass tubes is inserted in the forward part of the nostril and the subject draws his breath in the way most natural to him in smelling—the proportion of odorous particles is greater, however, when the current of air is slow than when it is rapid. The inside of the glass air tubes will need to be cleaned of adhering odorous particles from time to time.

On the olfactometer and its method of use see the following papers of Zwaardemaker: Die Bestimmung der Geruchschärfe, Berliner Klin. Wochenschrift, XXV, 1888, No. 47, p. 950 (abstract of the same, British Med. Journal, 1888, ii, 1295); also Lancet, London, 1889, i. 1300. On an improved form adapted to liquid substances (and thus to substances of known and relatively simple chemical composition) see, Compensation von Gerüchen mittelst des Doppelreichmessers, Fortschritte der Medicin, VII, 1889, 725 ff.

54. Minimal odors. The keenness of smell may be tested with dilute solutions of odorous substances or with the olfactometer; it will be instructive to test by both methods. *a.* Tests with solutions. Pour small quantities of the solutions of oil of cloves described above into little wide-mouthed bottles, filling each to about the same height. Mark all in an inconspicuous manner. Set the bottles on a table a foot apart in a place where there is moderate circulation of air, in the order of the strength of their solutions, beginning with the water and following with the weakest solution and so on. Require the subject to smell of the bottles in succession without lifting them from the table, beginning with the water, and to indicate that in which he first recognizes a characteristic odor. If the solutions stand for any length of time where they are subject to evaporation it will be safer to prepare fresh ones before undertaking a new test. Other precautions will suggest themselves, as for example, the use of bottles of the same size and shape, and care in filling them that some of the solution is not left clinging near the mouth. The just observable solution will probably be found to lie between the 1:100 000 and 1:400 000. *b.* Tests with the olfactometer. Test the sides of the nose separately. Push the odor-tube on till its end is flush with that of the glass tube, insert the bent end of the latter into the nostril as described above, and gradually lengthen the exposed surface of the odor-tube till its odor is just discernable. Note in millimeters the length exposed.

On *a* cf. Bailey and Nichols, The Sense of Smell, Nature, XXXV, 1886-87, 74; Lombroso and Ottolenghi, *op. cit.* under Ex. 51. On *b* cf. Zwaardemaker, Sur la norme de l'acuité olfactive (olfactie), Archives Néerlandaises, T. XXV, pp. 131-148.

55. Discriminative sensibility for odors. Using the double olfactometer with both odor-tubes drawn out far enough to give an unmistakable odor, but not too strong a one, say both drawn out 5 cm., find how far one or the other must be drawn out (or pushed back) to make the odor which it gives just observably stronger (or weaker) than that of the other. The test should be made with one side of the nose only, (there is frequently a difference in sensitiveness between the two sides, due to mechanical obstruction or other cause) unless for some reason a bilateral form of experiment is desirable. Try a number of times, but be careful to avoid fatigue.

56. Fatigue of smell. *a.* Hold a piece of camphor gum to the nose, and smell of it continuously, breathing in through the nose and out through the mouth, for five or ten minutes. A very marked decrease in the intensity of the sensation will be observed, reaching perhaps even to complete loss of the odor. *b.* It is important, however, to observe that fatigue for one substance does not cause obtuseness for all other substances, though it does for some. Smell of some essence of cloves and of some yellow wax, then fatigue for camphor as in *a* and smell of the essence of cloves and of the wax again. The odor of the wax will probably be fainter, that of the essence of cloves unaffected.

Cf. Aronsohn, Experimentelle Untersuchungen zur Physiologie des Geruchs, DuBois-Reymond's Archiv, 1886, pp. 321-57.

57. Compensation of odors. *a.* Experiment with the olfactometer on one side of the nose as follows. Hold against the end of the rubber odor-tube another odor-tube of wax, partly covered on the inside by a glass tube of the same size as that used in the olfactometer, in such a way that the air must pass through both to reach the nose. Then gradually increase the length of the rubber tube exposed till the odor of the

wax is no longer perceived. If the experiment is carefully performed a point may be found where the two odors nearly compensate and the resulting sensation approaches zero. If the rubber is lengthened beyond this point its odor overpowers that of the wax; if it is shortened it is overpowered by that of the wax. A *mixture* of the odors is hardly to be found. *b*. Repeat the experiment, using the double olfactometer with rubber on one tube and wax on the other. The compensation will be observed as before though each side of the nose receives a separate stimulus. If the two sides of the nose are not equally keen scented the proportions of the tubes that give compensating odors will not be the same as before. Care should of course be taken to avoid fatigue.

Cf. Zwaardemaker, Compensation von Gerüchen mittelst des Doppelreichmessers. Fortschritte der Medicin, VII, 1889, No. 19. pp. 721-731.

On smell in general, beside the literature already cited cf. von Vintschgau, Physiologie des Geruchssinnes, Hermann's Handbuch der Physiologie, III, (pt. 2) pp. 225-286, and the literature there cited.

IV.—HEARING.

SOUNDS IN GENERAL.

Apparatus. A watch, 2 yards of three-eights inch rubber tubing, 2 tuning-forks (the ordinary A forks sold at music stores at 25 cents each will answer if a couple are chosen that prolong their sound well), and a hammer. A watch is not an ideal instrument for testing acuteness of hearing, but has the advantage of ready accessibility and simplicity in use.

For other special instruments for testing acuteness of hearing cf. Hensen, Physiologie des Gehörs, Hermann's Handbuch der Physiol. III, pt. 2, pp. 119-120 and the references there given; also Jacobson, Ueber Hörprüfung und über ein neues Verfahren zur exacten Bestimmung der Hörschwelle mit Hülfe elektrischer Ströme, Du Bois-Reymond's Archiv, 1888, 189. For apparatus for testing the discriminative sensibility for sounds cf. (for noise) Starke, Die Messung von Schallstärken Wundt's Philos. Studien, III, 1886, 266, and Zum Mass der Schallstärke *Ibid*, V, 1889, 157; (for tone) Wien, Ueber die Messung der Tonstärke, Inaug. Diss. Berlin, 1888, also in Wiedemann's Annalen, XXXVI, 1889, 834—857.

On hearing in general cf, Helmholtz, Sensations of Tone, Eng. tr. by Ellis, Hensen, *op. cit.;* Stumpf, Tonpsychologie; Wundt, Physiologische Psychologie.

58. Minimal sounds. *a*. Experiment in a large room, furnished (to lessen the echoes) and as free as possible from noise. Let the subject be seated with his side toward the experimenter, his eyes closed and his ear upon the other side plugged with cotton. Let the experimenter then find what is the greatest distance at which the subject can still hear the tick of a watch held at the level of his ear and on the prolongation of the line joining the two. This is easily done with sufficient accuracy by drawing a chalk line on the floor, marking off feet or meters and fractions upon it and estimating by eye the point of the line directly under the watch. Try several times for each ear both when the watch is being brought toward the ear and when it is being carried away. The experimenter should from time to time cover the watch with his hand to discover whether or not the subject really hears or is under illusion. For normal ears the distance found may vary from 2.5 m. to 4.5 m. and may even rise to as much as 9 m. *b*. The subject should notice in this experiment the very marked intermittences of the sound when just upon the limit of audibility. It will for a few seconds be heard above doubt and a few seconds later will as certainly not be heard.

On *a* cf. von Bezold, Schuluntersuchungen über das kindliche Gehörorgan, Zeitsch, f, Ohrenheilkunde, XIV, 1884-85, and XV, 1885-86. This paper gives the results of numerous tests on Munich school children, not only with the watch but also with the acoumeter of Politzer and with whispered speech. On *b* cf. Urbantschitsch, Ueber eine Eigentümlichkeit der Schallempfindungen geringster Intensität, Centralblatt f. d. medic. Wissensch., 1875, 625; N. Lange, Beiträge zur Theorie der sinnlichen Aufmerksamkeit und der activen Apperception, Wundt's Philos. Studien, IV, 1888, 390; Münsterberg, Schwankungen der Aufmerksamkeit, Beiträge zur experimentellen Psychologie, Heft 2, 1889, 69.

59. Auditory fatigue. Cause an assistant to strike once with a hammer on the floor, or to clap his hands. With the ears open a single

sound, or at most a single sound and transient echoes are heard. If, however, the ears are kept closed with the fingers till half a second or more after the stroke (the time may easily be fixed by rapid counting), the fainter echoes will be heard like a new stroke. In the first case, fatigue from the original sound deadens the ears to the fainter echoes, though they may still be heard by attentive listening; in the second case they are more strongly heard because the closed ears are unfatigued. The sound produced by the simple opening of the ears without any objective stroke will be less if the finger is not put into the ears, but presses the *tragus* back upon the opening. *b*. Insert in the openings of the ears the ends of a rubber tube. Strike a tuning-fork and set it upon the tube at such a point that it sounds equally intense to the two ears. (The sound will then probably appear to be located in the head midway between the ears—at least not nearer one than the other). After a few seconds strike the tuning-fork again, pinch the tube on one side, say the left, so as to shut off the sound from the ear on that side, set the tuning-fork on the tube and keep it there till the sound has become rather faint. Then allow the pinched tube to open and notice that the sound is now stronger on the left than the right and apparently located on the left. Cf. later experiments on the location of tones.

On *a* cf. Mach, *op. cit.* (under Ex. 39) p. 58. On *b* cf. Urbantschitsch, Zur Lehre von der Schallempfindung, Pflüger's Archiv, XXIV, 1881, 574-579 and references there given. See also Stumpf, Tonpsychologie, I, 360-363, where other instances of fatigue are cited.

60. Inertia of the auditory apparatus. *a*. Inertia tending to keep the auditory apparatus out of function can be demonstrated as follows. Place the ends of a rubber tube in the ears and set upon the middle of it a low tuning-fork sounding as faintly as possible. Notice that the sound does not reach its maximum intensity for an appreciable length of time; if the fork is barely audible this may be as much as a second or two. Be careful not to increase the pressure of the fork upon the tube after first setting it on; for that will produce an objective strengthening of the tone; and allow an interval of several seconds between the tests so that the auditory apparatus may again come completely to rest. A tuning-fork that will preserve these minimal vibrations for some seconds and complete freedom from distracting noises will be found necessary for success.

Cf. Urbantschitsch, Ueber das An- und Abklingen acustischer Empfindungen, Pflüger's Archiv, XXV, 1881, 323.

61. Noise. Whether or not there is a distinctive sensation of noise different from that of a mass of short, dissonant and irregularly changing tones is yet under debate, with something of the weight of authority in favor of such a sensation. A little attention to the noises constantly occurring, especially to their pitch, will easily convince the observer that a tonal element is present. This is striking when resonators (cf. notes on apparatus for simultaneous tones) are used, for they pick out and prolong somewhat the tones to which they correspond, but they are not indispensable. On the other hand, attention to musical tones will often discover the presence of accompanying noises.

Cf. Wundt, Physiologische Psychologie, I, 420; Stumpf, Tonpsychologie, II, 497-514; also Brücke *op. cit. sub* 69; Exner, Pflüger's Archiv XIII, 288 ff.; Mach, Analyse der Empfundungen, Jena, 1886, 117.

62. Silence. When circumstances promise absence of external sounds, notice that many are still present and distinct, though faintly heard. Notice also the pitch and changing character of the subjective sounds to be heard. Our nearest approach to the sensation of absolute stillness is this mass of faint inner and outer sensations.

Cf. Preyer, Ueber die Empfindung der Stille, Sammlung physiologischer Abhandlungen, Jena, 1877, pp. 67-72. This section on Silence is a portion of Preyer's study, Ueber die Grenzen der Tonwahrnehmung.

SINGLE AND SUCCESSIVE TONES.

Though musical terms are occasionally used in these experiments and some discrimination of tones is necessary, it is believed that nothing is required beyond the average ability of the unmusical.

Apparatus. The upper limit of pitch may be tested with the disk siren, with tuning-forks, with steel cylinders and with little whistles of adjustable length. The last two instruments are most commonly used and may be had from almost any dealer in physical apparatus, the cylinders from $10 upward, the whistle (designed by Galton), at about $5.00. The Cambridge Scientific Instrument Co., St. Tibb's Row, Cambridge, Eng., makes the whistle in two patterns, a simple one at £1. 5s and a more elaborate one at £6. R. König, 27 Quai d'Anjou, Paris, also makes two kinds, one at 12 the other at 20 fr., the latter probably a better instrument than that of the Cambridge Scientific Instrument Co. at £1. 5s. For description and prices of the more expensive kinds of apparatus consult König's catalogue.

For testing the lower limit of pitch large tuning-forks may be used or the difference tones of small tuning-forks or of stopped organ pipes. Large tuning-forks could probably be made well enough for demonstrative purposes by almost any blacksmith and their pitch determined approximately by making them record their vibrations graphically upon a piece of smoked glass for ten seconds. The large fork with sliding weights (24-16 double vibrations per sec.) manufactured for this purpose by König costs 300 fr. and his set of high pitched forks for the difference tone method costs 340 fr.

For Ex. 65 and others that follow, almost any musical instrument of a considerable range of pitch will answer.

For Ex. 65*c*. use a piston whistle such as is sold in toy stores at five cents. Two that are in the laboratory here reach the proper pitch when their pistons are pushed in as far as possible. It would be easy, if still higher tones were needed, to so alter the whistles as to make these possible.

For Ex. 67 prepare a series of forks each differing from the next by about three vibrations a second. Half a dozen C forks such as are sold at the music stores will answer, if those are chosen that prolong their sound well. Take one of them as a standard and make the next sharper by filing a little at the free end of the prongs till it beats (cf. Ex. 75) with the standard three times in a second. Count for 10 seconds, if possible, and divide the total count by 10 to find the rate per sec., counting the first beat nought. (For precautions to be used in attempting an accurate count cf. Helmholtz, *op. cit.* 443 where Ellis gives all necessary particulars.) Having brought this fork approximately to three beats per sec. take it as a standard and make the next fork three beats sharper than it in the same way and so on. Make also a series o forks differing by three vibrations each, which shall be flatter than the normal C. It will be well to make a recount for greater accuracy after the forks have had a chance to cool. In order to flatten the forks a little as mentioned in Ex. 67 little riders of rubber tubing may be placed upon the prongs. Make these riders by cutting off quarter inch bits from tubing that will fit tightly upon the prongs of the forks. For the resonance bottles mentioned in the same experiment take a four ounce wide mouthed bottle and tune it to the forks by gradually closing its mouth with a bit of glass (*e. g.* a microscope slide). When the amount of closure is found which gives the greatest intensity of sound, fix the glass in position with wax. (For picture and description of such bottles see Meyer, *Sound*, pp.102-103). A standard instrument for giving such small differences of pitch as are represented above by the sharpened forks is made by Anton Appunn of Hanau a. M. under the name of a *Tonmesser*. (See picture and description in Wundt's Physiologische Psychologie, I,

431 f.) and costs for the complete instrument, with pitches ranging from 32 to 1024 vibrations per sec. and a blowing table, 1060 marks. Single octaves without the blowing apparatus range in price from 150 to 320 marks. The same maker also offers a set of forks giving a series of tones differing each from the next by a small fraction of a vibration (*Ton-differenz-apparat*) at 96 marks. See his price list also for other apparatus useful in the experiments of this section.

For Ex. 69 a hydrogen generator (cf. an elementary chemistry) will be necessary. In blowing the hydrogen and air bubbles it will be found convenient to have the mixed gases in one large bottle and to force them out by pouring in water.

For Ex. 70 a pint bottle.

Some of the apparatus suggested at the beginning of the next section will also be found useful in this.

63. Highest tones. With the apparatus at hand for the purpose, find what is the highest audible tone; i. e., if the cylinders are used, the shortest cylinder which still gives a ringing sound on the stroke of the hammer, or if the whistle is used, the closest position of the plunger at which a tone can still be heard beside the rush of air. If a number of persons are tested it is not improbable that some will yet hear the tone after it has become inaudible for the rest.

64. Lowest tones. *a.* If low pitched tuning-forks are at hand, find what is the slowest rate of vibration that can yet be perceived as a tone. In some physiological laboratories electric tuning-forks or interrupters are at hand which have vibration rates of 25 per second. Low tones can be heard from these, though they have many overtones. The latter can be partly damped by touching the tines mid-way of their length with the finger and partly avoided by bringing the ear not to the free end but to a point somewhat further toward the handle. The determination of the lower limit of audible pitch is difficult and uncertain because of the great difficulty which observers, even those of trained ear, find in distinguishing these lowest tones from their next higher octaves. *b.* The general character of these deep tones can be demonstrated with sufficient clearness upon the contra octave (C_1–C) of a church organ if one is accessible and tuning forks are lacking.

65. Some characteristics of high and low tones. *a.* High tones are smoother than low tones. This is clear with almost all tones used in music, and particularly so with those of reed instruments. It is largely due to the beating of the partial tones (see Exs. 82 ff. and 75 ff.) among themselves and even with the fundamental tones. Play the scale of the instrument at hand from the lowest to the highest, or sing the ascending scale. The difference of roughness is observable also with simple tones, but only at lower pitches and is even there less marked. *b.* High tones except the very high, produce a more intense sensation in proportion to their physical intensity than do low tones. Strike a low tuning-fork in which the over-tones are to be heard and notice that the over-tones can be heard at a greater distance than the proper tone of the fork. *c.* Some high tones are particularly strengthened by the resonance of the outer passage of the ear. These generally lie between c^4 and c^5 and give to the tones of this octave a superior strength, and ear-piercing quality. They may be demonstrated easily with a small piston whistle like that mentioned above. Find by adjustment of the piston the point at which the tone is most piercing. Insert in the outer ends of the ear passages bits of rubber tubing half an inch long (which will change the resonance of the passage, making them responsive to a lower tone) and sound the whistle again. The piercing quality will be gone and the tone appear decidedly weaker. Remove the bits of tubing and sound the whistle as before; the original quality and intensity reappear.

d. Very closely associated with the pure tonal sensations are certain of a spatial quality. Compare in this respect the sensations of the tones observed in Ex. *c* above, or better still those of Ex. 63, with those of Ex. 64 or any other deep tones. Play the scale through the complete compass of any instrument, keeping this quality in mind. *e.* The emotional shading of tones changes with their pitch. Recall the descriptive terms used: Deep, low, tuneful, sharp, acute. Play the scale and judge of the appropriateness of these terms to match the shades of feeling that mark the tones of low, middle and high pitch, distinguishing those that refer to pitch from those enumerated in Ex. 86 which refer to timbre.

Cf. Stumpf, Tonpsychologie, I, 202-218, II, 56-59, 514 ff.; also Mach, *op. cit.* under 61, p. 120 ff. On *c* and *e* cf. Helmholtz, Sensations of Tone (2nd Eng. ed) p. 179 and p. 69. On *d* cf. James, Psychology, II, 134 ff.

66. Recognition of absolute pitch. This experiment can, of course, give accurate results only with those of very decided musical ear and skill, but it may be tried with any subject that knows the names of the notes. *a.* Strike various notes in different parts of the scale of the instrument and require the subject to name the note given. Record the note struck and the subject's answer. He should be seated with his back toward the experimenter or should keep his eyes closed.

Cf. Stumpf, *op. cit.* I, 305-313, also II, index, *Höhenurteile*, for experiments on trained musicians.

67. Just observable difference in pitch. *a.* Test as follows with the set of mistuned forks mentioned above. Let the subject pick out from the mistuned forks that which sounds to him most like the normal fork, striking and holding them successively (never simultaneously) over a resonance bottle. If all of them seem more than just observably different let him put the riders (described above) on the one that is next higher and gradually lower the pitch by sliding them toward the ends of the fork till the two, heard successively, are just different and no more. The experimenter may then determine the error of the subject in vibrations per second approximately by counting the number of beats produced by the forks when sounded together. If the number of beats per second is less than 2 or more than 6 it will be best to get the difference in pitch with some other of the forks first, so as to avoid too slow or too rapid counting, and from that to arrive at the difference from the standard fork. Repeat the test several times and average the result, but take care to avoid fatigue. This experiment will not be refined enough for testing those of keen musical ear.

Cf. Preyer, Grenzen der Tonwahrnehmung, Sammlung physiologischer Abhandlungen, I, (Jena, 1877) 26 ff.; Stumpf. *op. cit.* I, 296-305; Luft. Wundt's Philos. Studien, IV, 514.

68. Differences in pitch that are just recognizable as higher or lower. It is easier to recognize a difference than to tell its direction. *a.* Experiment as in 67*a*, but require the subject this time to pick out and adjust a fork that is just observably sharper or flatter than the standard.

On *a* cf. Preyer, *op. cit.* 28, 36. For experiments on extremely unmusical subjects cf. Stumpf, *op. cit.* I, 313-335.

69. Number of vibrations necessary to produce a sensation of pitch. Arrange an apparatus for blowing soap-bubbles with a mixture of hydrogen and air. Blow bubbles of different sizes and touch them off with a match, either in the air, or, if proper precaution is taken to prevent the ignition of the mixed gases in the vessel and any resonance in the pipe, while still hanging. The explosion of these bubbles is supposed to produce a single sound wave. The pitch of the sounds produced cannot be accurately given, but the report of the large bubbles is distinctly deeper than that of the small ones.

Cf. Brücke, Ueber die Wahrnehmung der Geräusche, Wien. Sitzb., 3te Abth., XC, 1884, 199-230.

70. The apparent pitch of tones is affected by their timbre, tones of dull and soft character regularly seeming lower in pitch than those that are brighter and more incisive. Require the subject to pick out on some stringed or reed instrument the tone corresponding to that produced by blowing across the mouth of a medium sized bottle. Too low a note will generally be chosen, at least by those without special musical training. The tones should be sounded successively, not at the same time, during the test. Afterward they may be sounded together and the pitch of the bottle determined approximately by finding with which tone of the instrument its tone makes the slowest beats (cf. Ex. 75). It should be remembered, however, that it will be possible to get beats also with tones an octave lower and an octave higher than that corresponding most nearly with the true pitch of the bottle tone. *b*. Repeat the experiment, taking the pitch of the bottle first with the voice and then finding the tone on the instrument corresponding to that sung. The illusion will probably disappear when the test is thus made.

Cf. Stumpf, *op. cit.* I, 176, 227-247, especially, 235-245.

71. Recognition of musical intervals. Cause a familiar air to be played, first in the octave of *c* and then in that of c'' in the same or another key. Even those of no musical training will easily recognize that the air (i. e. the succession of musical intervals in fixed rhythmical relations) is the same in both cases; and any mistake or variation will be noticed as easily as if the air had been repeated at the first pitch. The power of recognizing intervals is very much more highly developed in persons of musical training, but any one that can whistle a tune at one pitch and repeat it recognizably at another undoubtedly has the rudiments of it.

For exact methods of testing the accuracy of the power of recognizing intervals cf. Preyer, Ueber die Grenzen der Tonwahrnehmung, Jena, 1876, pp. 38-64; and Schischmánow, Untersuchungen über die Empfindlichkeit des Intervallsinnes, Wundt's Philos. Studien, V, 558-600 and the references there given.

72. Pitch distances. Beside the interval relations of tones, and overshadowed by them in musicians, are certain relations of separateness or distinctness or distance in pitch, which do not depend on the ratios of vibration rates. Equal musical intervals (i. e. intervals between tones that have vibration rates in a fixed ratio to each other, e. g. *C D* and c'' d'') do not correspond to equal pitch distances. Sound the half tone interval *cc*-sharp through the range of the instrument, beginning in the bass and ascending. Notice the increasing distinctness and separation of the tones as the interval is taken higher and higher. For the very highest tones there is probably a decrease of separateness again. The difference is most striking, however, with intervals smaller than those in common use, e. g. with quarter or eighth-tones. On the harmonical (cf. notes on apparatus at the beginning of the next section) strike in succession the *c-sharp* and *d* keys in the four lower octaves beginning with the lowest. In this instrument the *c-sharp* key is given to another *d*, a comma, or about one-ninth of a tone, flatter than the regular *d* of the scale.

Cf. Stumpf, *op. cit.* I, 249-253; Lorenz, Untersuchungen über die Auffassung von Tondistanzen, Wundt's Philos. Studien, VI, 1890, 26-103; also a prolonged discussion between Wundt and Stumpf (and Engel) in succeeding numbers of the Studien and in the Zeitschrift für Psychologie. Helmholtz, *op. cit.* pp. 264-65, 285, 287.

73. The effect of a given tone in a melody depends in part on the succession of tones in which it stands. Cause a simple air, in which the same tone recurs in different successions of tones, to be played and notice the difference in effect in the different circumstances.

Mach, *op. cit.* under 61, p. 130-131.

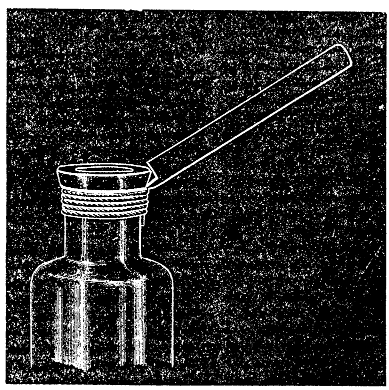
74. Tones that vary irregularly in time and in pitch are unpleasant. Test with a piston whistle.

SIMULTANEOUS TONES.

Apparatus. For the experiments of this section access to some large musical instrument is essential, and a reed instrument is to be preferred to a piano if only one is to be used. A parlor organ will answer in most cases, but sometimes the specially tuned Harmonical designed by Ellis to illustrate the theories of Helmholtz (see description of the instrument in his translation of Helmholtz's Sensations of Tone, pp. 466-469, also 17, 22 and 168), would be better. This instrument is made as an aid to science by Messrs. Moore and Moore, 104-105 Bishopsgate St., Within, London, E. C., at the very low price of from £8-5 to £10. For the proper tuning of the instrument, however, a set of 19 forks is necessary costing £3-10 extra. In many of the experiments a sonometer can take the place of a piano. A sonometer is simply a long flat box with a very thin top which serves as a sounding board for the strings that are stretched over it. One may be had from any physical instrument dealer at from $10.00 upward, or can be made by a carpenter. For directions for making and dimensions see Mayer, Sound, (Appleton & Co.) pp. 129-130.

For more perfect apparatus for the study of beats, difference tones, compound tones, timbre, etc., consult the catalogues of König, whose address has already been given, and of Anton Appunn, Nürnbergerstrasse 12, Hanau, a. M., Germany. Both make resonators, those in spherical form made by König are best and most expensive. A series of 10 corresponding to the first ten partial tones of c (128 vibrations) costs 110 fr.; a series of 19, 170 fr. Appunn's in conical form cost from 27 mk. for a set of 9 to 80 mk. for a set of 29.

The bottle whistles mentioned in Ex. 75 are easily made by fitting a piece of rubber tubing to the lip and neck of a bottle as in the cut, or better still, by slitting the tube a little way so that half the tube may extend an eighth or three-sixteenths of an inch over the lip, but care must be taken that it does not project too far.



A pair of octave tuning forks will also be needed. The large forks on resonance cases (to be had of any physical instrument dealer at a cost of from $5.00 to $20.00 according to pitch) are much to be preferred, because they sound longer after once being struck, but are not indispensable. A pair of octave forks can be made from an a' and a c'' fork by filing the a' till it gives c'. Choose an a' fork with thick and heavy prongs and file it in the crotch and along the lower half of the prongs inside, distributing the filing so as to leave the prongs of equal thickness, till it begins to beat with c'' when both are struck and have their stems pressed against the table. Then continue the filing carefully till the beats can no longer be heard. The filing warms the fork and makes it a little flatter than when cold; this of course must be taken into account. To make a c''' fork, if one is desired, a c'' should be used and the cutting must be at the free end of the prongs. In one made here about three-quarters of an inch was taken off. The tuning is as before by filing until the beats with c'' are first heard, then grow slower and finally disappear. In the same way an a'' may be made as the octave of a', but these small forks do not vibrate very long.

75. Beats. When tones not too greatly different in pitch are sounded at the same time they mutually interfere and make the total sensation at one instant more intense and the next instant less intense. This regular variation in intensity is called "beating." Exs. 67 and 70, where beats have been used incidentally, are a sufficient introduction to them. *a*. The rapidity of beats depends on the difference in the vibration rates of the beating tones. Prepare two bottle whistles of the same size and blow both at the same time. Slow beats will probably be heard. If not, pour a little water into one bottle (thus raising the pitch of its tone) and blow as before. Continue adding water a little at a time till the beats lose themselves in the general roughness of the tone. Blow the bottles separately now and then to observe the increasing difference in pitch. The same may be shown with a couple of piston whistles, if they are first adjusted to unison and then the piston of one or the other is slowly pushed in or pulled out. *b*. The rate at which the roughness of rapid beats disappears, as also the rate which produces the greatest roughness, differs with the pitch of the beating tones. Sound the following pairs of tones which have somewhat near the same difference in vibration rates per sec., namely, 33; and observe that the roughness from the beats decreases and finally disappears entirely at about the fourth pair: *b' c''*, *c' d'*, *e g*, *c e*, *G c*, *C G*. The *a'* and *c''* tuning forks give a vanish of roughness, representing a rate of 80-88 per sec.

Cf. Helmholtz, *op. cit.*, pp. 159-173; Stumpf. II, 449-497, especially 461-465.

76. Beats betray the presence of very faint tones both because the total stimulus is actually stronger in the phase of increased intensity and because intermittent sensations are themselves more effective than continuous ones. *a*. Strike a pair of beating tuning-forks and hold one at such a distance from the ear that it is very faint or quite inaudible. Then bring the other fork gradually toward the ear and notice the unmistakable beats. *b*. Strike a tuning-fork and hold it at a distance as in *a*, being careful to have the fork sidewise or edgewise, not cornering, toward the ear. Rotate the fork one way and the other about its long axis and observe the greater distinctness of the tone, due in this case simply to its intermittence.

77. Beats are in general attributed to the tone that is attended to; in the absence of otherwise determining causes, to the louder tone, if there is a difference in intensity, to the lower tone, or to the whole mass of an unanalyzed compound tone (see introduction to Ex. 82). *a*. Set two properly tuned resonance bottles about a foot apart on the table. Strike two forks that beat and hold them over the bottles. While both are about equally intense it is easy by mere direction of the attention to make the beats shift from one to the other. *b*. Turn one of the forks about an eighth of a turn about its long axis, which will weaken its tone and observe that the beats seem to come from the other fork. By moving first one fork and then the other the location of the beats may again be made to shift at pleasure. *c*. Warm the *c'* fork in any convenient way, (holding it clasped in the hand will do.) This will flatten it somewhat. Strike it and the *c''* fork and press the stems of both on the table at the same time, or better on the sounding board of the sonometer. Observe that the beats seem to come from *c'* fork unless it is very faint. *d*. Tune a string of the sonometer so that its third partial (or corresponding harmonic) beats slowly with the *c''* fork. (On partials and harmonics cf. Exs. 82-85.) Strike the tuning-fork and hold it over a resonance bottle, or press its stem against the table at arm's length from the string. Then pluck the string and attend to its tone, the beats may seem to affect the whole compound tone of the string. But this will not happen if the tone of the string is analyzed or if the attention is directed to the fork. The same may be tried on the piano

by picking out from the mistuned c'' forks one that beats slowly with c'' on the piano. Strike the f key and hold it down; strike the fork and observe the beats as before.

Cf. Stumpf, *op. cit.* II, pp. 489-497.

78. Difference tones.[1] When two tones are loudly sounded at the same time there results (probably from supplementary vibration of the tympanic membrane and ear bones) a third tone of a pitch represented by the difference of the vibration rates of the two original or generating tones. These difference tones are easy to hear when they lie considerably deeper than the generators, when the latter are loud and sustained, and when they make a consonant interval, though the latter is not essential. A loud difference tone may itself take the part of a generator and produce yet another difference tone—a difference tone of the second order—and so on, though difference tones of higher orders are heard with difficulty even by skilled observers of trained ear. Difference tones are hard to hear on the piano and similar stringed instruments, because of the rapid decline in the strength of the generators. *a.* Repeat Ex. 75 *a* continuing to pour water into one of the bottles till the difference tone appears. At first the roughness of the beats and the difference tone may both be heard at once. Try the same with the piston whistles, first setting them at unison and then slowly pushing the piston of one in or out while blowing hard. The beats will almost immediately give place to a low difference tone which may be heard ascending through several octaves before becoming indistinguishable from the generators. The double warning whistles used by bicyclists give a fine difference tone, to which indeed they owe their deep and locomotive like quality. *b.* Difference tones are strong on reed instruments. Press the adjacent white keys of a parlor organ, or the harmonical, by twos, beginning at *c* and going up a couple of octaves. If there is difficulty in hearing the difference tone, sound the upper tone intermittently and listen for the difference tone at the instant of pressing the key. *c.* Sound c'' and d'' which should give C for a difference tone (594—528=66). Sound also d'' and e'' which should give the same (660—594=66). If, however, the tuning is inexact, as it is intentionally in the tempered tuning of keyed instruments, these difference tones will be somewhat different and may be heard to beat with one each other when c'', d'' and e'' are sounded at once. Notice that you do not get these beats when the tones are sounded in pairs. On the harmonical this difference may be brought about by sounding one of the tones flat by pressing its key only a little way down. The same thing may be shown with three piston whistles blown at once, by a little careful adjustment of the pistons. *d.* The location of difference tones. The location of these tones is sometimes influenced by the location of their generators, but under favorable circumstances they seem to arise in the ears or even in the head. This is strikingly the case, both for the blower and the listeners, with the difference tones produced with the piston whistles.

Cf. Helmholtz *op. cit.*, pp. 152-159; Stumpf, *op. cit.*, II, pp. 243-257. König, Quelques expériences d'acoustique, Paris, 1882.

79. Blending of tones. The degree to which tones blend with one another differs with the interval relation of the tones taken. It is, according to Stumpf, greatest with the octave, less with the fifth, less again with the fourth, slight with the thirds and sixths and least of all with the remaining intervals. Try on the instrument the extent to which the tones forming these intervals blend, also those forming intervals greater than an octave: double octave, twelfth, etc. *b.* The blending in

---

[1] König distinguishes between "difference tones" and "beat tones." Both tones, however, generally have the same pitch and the older term for them has here been retained; strictly speaking, however, the "difference tones" heard in these experiments are "beat tones."

case of the octave is so complete under favorable circumstances as to escape the analysis of trained ears. Use two tuning-forks, one an octave higher than the other, on resonance cases or held over resonance bottles. Sound the forks, first the higher, then the lower. For a while the higher fork will be heard sounding in its proper tone, but by degrees it will become completely lost in the lower and a subject with closed eyes will be unable to say whether or not it yet sounds. Stop the lower fork or remove it from its resonance bottle and notice that the higher is still sounding. Notice the change in timbre (cf. Ex. 86) produced by the stopping of the higher fork—something like the change from the vowel O to the vowel U (oo).

On *a* cf. Stumpf, *op. cit.* II, pp. 127-218, especially 135-142, 353; for his experiments on the unmusical confirming his grades of blending cf. 142-173. On *b* cf. Stumpf, *op. cit.* II, pp. 352-356, and Helmholtz, *op. cit.* pp. 60-61.

80. Analysis of groups of simultaneous tones. Ease of analysis depends on a number of conditions, among others on the following. *a.* Analysis is easier for tones far distant in the scale. Compare the ease of recognizing the sound of the c'' fork when c' and c'' are sounded together, with that of recognizing c''' when sounded with c'. Compare also the ease of distinguishing c' and a' with that of distinguishing c' and a''. *b.* Analysis is made easier by loudness in the tone to be separated. Repeat Ex. 79 *b* sounding the c' faintly the c'' strongly. No difficulty will be found in keeping the latter distinct. *c.* Analysis is easier when the tones make intervals with little tendency to blend. Compare the ease of analysis of c' c'' and c' a' or a' c''. Also notice that the addition of d'' (octave of d', fifth of g', fourth below g'') to the chord g d' g' g'' produces a less striking change than the addition of b' (major third of g', minor sixth below g''). *d.* Analysis is easier with sustained than with short chords. Repeat the last experiment making the chords very short and notice that the difference made by inserting either d'' or b' is less marked. Cf. also Ex. 95.

Cf. Stumpf, *op. cit.* II, 318-361, also his experiments, 362-382.

81. The lower tone of a chord fixes the apparent pitch of the whole. *a.* Repeat Ex. 79 *b* and notice that when the c' fork is stopped the tone appears to jump upward an octave in pitch (i. e. it takes the pitch of the c'' still sounding); but when the c'' fork is removed the quality of the tone is changed but not its pitch. *b.* Strike the chord C c'' e'' g'' or G e' g' c'' and compare the effect upon the pitch of the whole mass of tone produced by omitting C or G alone with that of omitting any one or all three of the higher tones. See also the function of the lowest partial of a compound tone in fixing the pitch, noticed below.

Cf. Stumpf, *op. cit.* II, 383-392.

Compound tones which on casual hearing seem single tones but in reality are chords deserve special attention. The tone given by the C string of a piano is made up of at least C, c, g, c', e' and g' and generally other tones. The lowest tone of the group gives the pitch attributed to the whole and is known as the *fundamental*, the other tones as *over-tones.* In another way of naming them, the component tones are all *partial tones* or *partials*, the fundamental being called the *first* or *prime partial*, the next higher the *second partial* and so on. It should be observed that the *first* over-tone is the *second* partial tone, the *second* over-tone the *third* partial, and in general that the same tone receives as a partial tone a number one higher than as an over-tone. The vibration rates of the partial tones of a compound are generally once, twice, three times, four times, the rate of the fundamental, and so on. In some cases, however, *e. g.* in bells and tuning-forks one or more of the partial tones may have vibration rates not represented in this series and discordant with the

fundamental tone. In what follows, the regular series of partial tones is meant except where the contrary is specified.

On the physics and physiology of this matter and others treated in this and the preceding section cf. Tyndall, On Sound; Blaserna, Theory of Sound in its Relation to Music; Taylor, Sound and Music; Helmholtz, Sensations of Tone. The last is of course the great classic on all such matters; the next to the last is very simple and untechnical and perhaps the best for those approaching the subject for the first time.

82. Partial tones: Analysis with resonators. If resonators are at hand the demonstration of the partial tones will be easy. Sound on the instrument the tones to which the resonators are tuned, and notice that they resound strongly to these tones and less strongly or not at all to other tones adjacent in pitch. Then sound the tone to which the largest of the resonators is tuned, and try the rest of the resonators in succession. Notice that others also resound (at their own proper pitch), thus betraying the presence of the tones to which they are tuned, and thus the composite character of the tone under examination. Which resonators will "speak" will depend on the instrument used, reed instruments giving a long and perfect series, pianos and stretched wires a perfect series generally as far as the 9th or 10th partial, and stopped organ pipes a short series. If difficulty is found in knowing when the resonator is resounding, it will be found useful to apply it to the ear intermittently, alternating, for example, two seconds of application with two seconds of withdrawal.

83. Partial tones: Analysis by indirect means. *a.* By sympathetic vibration. This succeeds especially well with the piano. Press the *c* key and hold it down so as to leave its strings free to vibrate; then strike the *C* key forcibly and after a couple of seconds release it. The *c* strings will be found to be sounding. Repeat, trying *c-sharp* or *b* instead of *c*; they will be found not to respond. Repeat the experiment, substituting g, c' e' g', and c''; all will be found to respond but in lessening degrees. Other keys between C and c'' may be tried but will be found in *very* faint vibration, if at all. *b.* By beats. This will succeed best with a reed instrument, e. g., a parlor organ or the harmonical. By pressing the keys of the instrument only a little way down any of its tones may be sounded a little flatter than its true pitch and so in condition to beat with any other tone having that true pitch. Sound at this flattened pitch the over-tones of *C* in succession while *C* is sounding, and notice the slow beats that result. For verification sound other tones not over-tones of *C* and notice that the beats when present are much more rapid.

84. Partial tones: Direct analysis without special apparatus. The directions given here apply to the sonometer, but will be readily adaptable to any stringed instrument in which the strings can be exposed. It is easier to hear any partial tone in the compound, if the partial is first heard by itself and then immediately in combination with the rest. On strings this is easily done by sounding the partials as "harmonics." Pluck the string near one end (say about one-seventh of the length of the string from the end), and immediately touch it in the middle with the finger or a camel's-hair brush. The fundamental will cease to sound and its octave (the second partial) will be left sounding, as an "harmonic." With it sound also other even-numbered partials, but less strongly. Pluck as before and touch the string at one-third its length; the third partial will now sound out strongest, with the sixth, ninth, etc., more faintly. Thus by plucking the string and touching it respectively at one-half, one-third, one-fourth, one-fifth, one-sixth, one-seventh, one-eighth, one-ninth and one-tenth its length from the end, the series of tones corresponding to the 2d, 3d, 4th, 5th, 6th, 7th, 8th, 9th and 10th partials can be heard, each in large measure by itself. In getting the higher "harmonics" it will be found better to pluck nearer

the end than one-seventh, and in no case should the string be plucked at the point at which it is presently to be touched. (cf. Ex. 86 *b*.) To hear the partial tones when sounding in the compound, proceed as follows. Sound the required tone as an "harmonic," and then keeping the attention fixed on that tone, stop the string and pluck it again, this time letting it vibrate freely. The tone just heard as an "harmonic" will now be heard sounding with the rest as a partial. When the partial is thus made out, verify the analysis by touching the string again and letting the tone sound once more as an "harmonic." Try in this way for the partials up to the tenth; first for the 3d, 5th and 7th, afterward for the 6th, 4th and the 2d, which is the most difficult of all. It has been said that analysis is easier at night, (not alone on account of the greater stillness), when one ear is used, and that certain positions of the head favor certain partials.

85. Partial tones: Direct analysis without apparatus. Certain parts of a compound tone are sometimes so separated by their dissonance, intensity or pitch that they stand out with striking clearness. *a.* Strike a tuning fork on a hard surface and observe the high, ringing, dissonant partials. They fade out before the proper tone of the fork, and are heard best when the fork is not held near the ear. *b.* As the tone of a string is allowed to die away of itself, different partial tones successively come into prominence. Try with a low piano string, keeping the key pressed down while the sound fades, or on the sonometer. Something of the same kind, but less marked, happens in the dying away of a low tone on a reed instrument when the air is allowed to run low in the bellows. *c.* When a tone is sounded continuously for some time, for example, on a reed instrument with one of the keys clamped down, different partials come successively into prominence, either through varying fatigue or the wandering of attention.

Cf. Helmholtz, *op. cit.* pp. 36—65; Stumpf, *op. cit.* II, 231—243, see also the index under *Obertöne*.

86. Timbre. The peculiar differences in quality of tones, (distinct from pitch and intensity,) which are known as differences in timbre (tone color, clang tint, *Klangfarbe*), are due to differences in the number, pitch and intensity of the partial tones present. Compare in this respect the dull-sounding bottle tones or the tones of tuning forks held over resonance bottles and the more brilliant tones of a reed or stringed instrument; the first are nearly simple tones, while the second have strong and numerous over-tones. *a.* Notice the difference in quality between the tone given by a tuning fork held before the ear and that given by the same fork when its stem is pressed upon the table. In the second position the over-tones are relatively stronger. *b.* Notice the differences in quality in the tone of a string when it is plucked in the middle, at one-third its length and at about one-seventh. When plucked in the middle, many odd-numbered partials are present and the even-numbered partials are either absent or extremely faint, and the tone is hollow and nasal; when plucked at one-third, the third, sixth and ninth partials are wanting and the tone is hollow, but not so much so as before; when plucked at one-seventh all the partials up to the seventh are present (for their theoretical intensities cf. Helmholtz *op. cit.* p. 79). *c.* Try also plucking very near one end, plucking with the finger-nail and striking the string with a hard body, e. g., the back of a knife blade; all these bring out the higher and mutually discordant partials strongly and produce a brassy timbre. Cf. also Ex. 79 *b*.

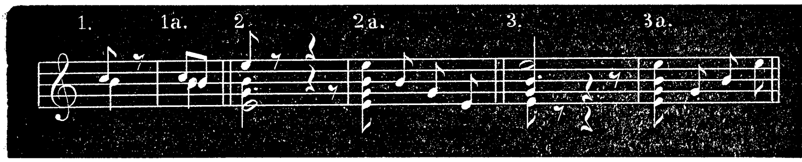
Cf. Helmholtz, *op. cit.*, pp. 65—119; Stumpf, *op. cit.*, II, 514—549.

87. In successive chords the whole mass of tone seems to move in the same direction as the part that changes most. Strike in succession the chords *e′ g′-sharp b′ e″*, *a a′ c″-sharp e″* or *a c′ e′ c″*, *a c′ f′ c″*. If the attention is directed to the bass in the first example and to the alto

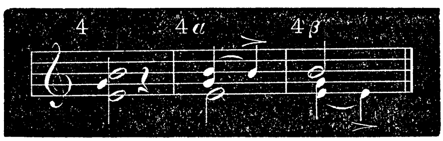
in the second the whole mass of tone will appear to descend in the first case and to ascend in the second. If the attention is kept on the soprano part the illusion will not appear, as also when the observer examines his sensations critically. Cf. also Ex. 77 *d* where beats of a partial tone are attributed to the whole compound tone.

Cf. Mach, Analyse der Empfindungen, 1886, 126–127; Stumpf, *op. cit.*, II, 393–395.

88. Simultaneous tones interfere somewhat with one another in intensity.



a. Play the groups of notes numbered 1, 2 and 3 and observe the slight increase in the apparent intensity of the remaining tones as one after another drops out, making 1 sound like 1a, 2 like 2a, and so on. On the piano it will be well to play the notes an octave or two deeper than they are written.



b. Play the notes marked 4 and notice that the increase of loudness seems to affect the note (highest or lowest) that receives particular attention, making the effect in one case like 4*a*, in the other like 4*β*.

Cf. Mach, *op. cit.* 126; Stumpf, *op. cit.*, II, 418—423.

89. Consonant and dissonant intervals. *a.* The consonant intervals within the octave are the unison, octave, fifth, fourth, major sixth, major third, minor third, minor sixth. They will be found to decrease in smoothness about in the order given. Try them beginning with the octave and at *c*, as follows: *c c'*, *c g*, *c f*, *c a*, *c e*, *c e-flat*, *c a-flat*. Try the last four intervals also in the octave of *c''* or *c'''* and notice that they are less rough than when taken in the octave of *c*. Any other intervals within the octave are dissonant. Try *c c-sharp*, *cd*, *cb*, *cb-flat*, *c f-sharp*. The roughness is due to beating partial tones and in general is greater when these stand low in the series and are loud, and when they lie within a half-tone of each other. Work out for the tones of several of the intervals the series of partial tones up to the eighth. In general the extension of intervals into the second octave (taking the higher tone an octave higher or the lower tone an octave lower) does not change the fact of consonance or dissonance, though it may change the relative roughness. *b.* Those fitted by musical training to pronounce upon questions of consonance and dissonance hold that dissonance can be perceived between simple tones under conditions that exclude beats, and that consonance is not simply the smooth flowing of tones undisturbed by beats. The test is easy to make—simply to hold tuning forks making the intervals to be tested one before each ear, and if there are beats to carry the forks far enough away in each direction to make the beats inaudible—but only those of musical ear can pronounce upon the result.

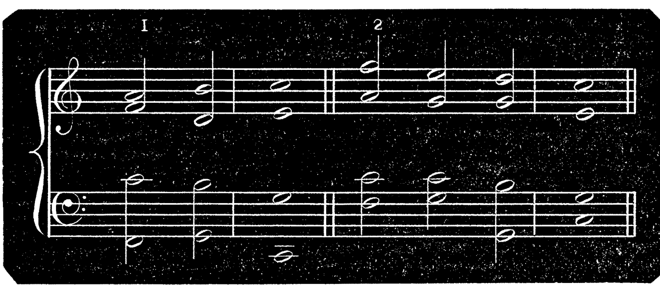
Cf. on *a*, Helmholtz, *op. cit*,, pp. 179–197. Stumpf, *op. cit.* II, 470, 460. Wundt, Physiologische Psychologie, I, 439, II, 47 ff.; Mach, *op. cit.*, 129—130.

90. Consonant and dissonant chords. In order to form a consonant chord all the intervals between the tones used must also be consonant. The only chords of three tones which fulfil this condition within the octave are represented by the following: Major *c e g*, *c f a*, *c e-flat a-flat*, minor *c e-flat g*, *c f a-flat*, *c e a*. Try these and for comparison any other chord of three tones having *c* for its lowest tone.

Cf. Helmholtz, *op. cit.* p. 211 ff.; Wundt, *op. cit.* II, 61, 67 ff.

91. Major and minor chords. Compare the chords c'' e'' g'' and c'' e''-*flat* g''. This unmistakable difference in effect depends in part at least on the fact that in the major chord the difference tones of the first order are lower octaves of c'' itself, while in the minor chord one difference tone is not such at all and if taken in the same octave with the chord would be highly dissonant. For the major chord, when taken in the octave of c'', the difference tones are *c* and c'', for the minor chord *c*, *e-flat*, *A-flat*. Try on a reed instrument the difference tones generated by c'' e'', e'' g'', c'' e''-*flat*, e''-*flat* g'', first separately; and then while c'' and g'' are kept sounding, strike e'' and e''-*flat* alternately.

92. Cadences. Modern music requires the prominence of the key note or tonic and of the chord in which it holds the chief place at the beginning of a piece of music and at the end. The feeling of the appropriateness of this close and especially of the succession of chords in the following cadences can hardly fail to appeal even to the unmusical.



Cf. Helmholtz, *op. cit.*, 293.

BINAURAL AUDITION AND THE LOCATION OF SOUNDS.

Apparatus. In addition to apparatus already used, a pair of unison tuning-forks on resonance cases will be needed in Ex. 96 *d*, (and in several of the other experiments such large forks, unscrewed from their cases, are almost indispensable, because the tones of ordinary small forks are too faint and last too short a time), also a mechanical telegraphic "snapper-sounder," a yard-stick and a retort stand. The "snapper sounder," common as a toy a few years ago, can be bought of E. S. Greeley & Co., 5 & 7 Dey St., New York, at from 30 to 75 cents.

93. Unison tones heard with the two ears. *a.* Strike a pair of unison forks that will sound equally loud and vibrate an equal length of time, and hold one before each ear, three or four inches away; a single tone of rather indefinite location will be heard. As the forks are brought nearer, their tone seems to draw by degrees toward the median plane; and when they are very loud and near, the tone may seem to be in the head. Return the forks to their first position and then move one a little nearer or a little farther away, and notice that the sound moves to the side of the nearer fork. When the difference in distance has become considerable that fork alone will be heard. *b.* Bring the forks again into the positions last mentioned—one near and one far, (or better, place one fork on a rubber tube one end of which has been inserted in

the opening of the ear and hold the other fork before the other ear), and then with the free or more distant fork make slow rythmical motions toward and away from the ear, or rotate the fork slowly about its long axis, attending meantime to the fork on the other side. Alternate variations in the intensity of the tone of this fork corresponding to the approach and recession of the other and apparently unheard fork can be heard. *c*. Repeat *b* and notice that when the changes in intensity are considerable there is a simultaneous shifting of the place of the tone, toward the median plane when the tone grows stronger, and away when it grows fainter. These changes of place are, however, less marked than changes in intensity and those accompanying slight changes in intensity generally escape observation.

Cf. Schaefer, Zur interaurealen Lokalisation diotischer Wahrnehmungen, Zeitschrift für Psychologie, I, 1890, 300-309; also Silvanus P. Thompson, On Binaural Audition, Phil. Mag. Series 5, IV (July-Dec., 1877) 274-276; VI (July-Dec., 1878) 383-391, XII (July-Dec., 1881) 351-355; On the Function of the two Ears in the Perception of Space, XIII (Jan.-June, 1882) 406-416; and the references given by these two authors.

94. Beats heard with the two ears. *a*. Operate as in Ex. 93 *a*, with forks beating three or four times a second. *b*. Try with a pair of very slow beating forks (once in two or three seconds). Notice a shifting of the sound from ear to ear corresponding to the rate of beating. *c*. Try again with a pair of rapid beating forks (twenty or thirty a second) and notice that the beats are heard in both ears.

Schaefer, *op. cit.* also Ueber die Wahrnehmung und Localisation von Schwebungen und Differenztönen, Zeit. f. Psy. I, 1890, 81—98.

95. Difference of location helps in the analysis of simultaneous tones. Compare the ease with which the tones of a pair of octave forks are distinguished when the forks are held on opposite sides of the head with the difficulty of analysis in Ex. 79*b*.

Cf. Stumpf, *op. cit.* II, 336, 363.

96. Judgments of the direction of sounds. These depend in general on the relative intensity of the sounds reaching the two ears, but there is pretty good reason to believe that other things co-operate and that tolerably correct judgments, both as to distance and direction, can sometimes be made from the sensations of one ear. *a*. Let the subject be seated with closed eyes. Snap the telegraph snapper at different points in space a foot or two distant from his head, being very careful not to betray its position in any way, and require him to indicate the direction of the sound. Try points both in and out of the median plane. Observe that the subject seldom or never confuses right and left but often makes gross errors in other directions. Constant tendencies to certain locations are by no means uncommon. *b*. Have the subject hold his hands against the sides of his head like another pair of ears, hollow backward, and try the effect upon his judgment of the direction of the snapper. *c*. Find approximately how far the snapper must be moved vertically from the following points in order to make a just observable change in location: on a level with the ears in the median plane two feet in front; opposite one ear, same distance; in the median plane behind the head, same distance. Find the just observable horizontal displacements at the same points. A convenient way of measuring these distances is to clamp a yard-stick to a retort-stand, bring it into the line along which measurements are to be made and hold the snapper over the divisions of the stick. Snap once at the point of departure, then at a point a little way distant in the direction to be studied; again at the first point, so that the subject may keep it in mind, and then at a point a little more distant, and so on till a point is finally found which the subject recognizes as just observably different. Repeat, alternating snaps at the point of departure with those at a greater distance than that just found, decreasing the latter till a point is found where the directions can be no longer distinguished. Make a number of tests each way and take their average.

d. Continuous simple tones are very difficult to locate. Place a tuning-fork on its resonance case at some distance in front of the subject (seated with closed eyes), another at an equal distance behind him. With the help of an assistant strike both forks and after a little have one of them stopped and the mouth of its resonance box covered. Require the subject to say which has been stopped. His errors will be very frequent. Compare with this his ability to distinguish whether a speaker is before or behind him.

Cf. on *a* Preyer, Die Wahrnehmung der Schallrichtung mittelst der Bogengänge, Pflüger's Archiv, 1887; also v. Kries, Ueber das Erkennen der Schallrichtung, Zeit. f. Psy. I, 1890, 235-251. On *c* cf. Münsterberg, Raumsinn des Ohres, Beiträge zur experimentellen Psychologie, Heft. II, 1889. Rayleigh, Nature, XIV, 1876, 32.

97. Intercranial location of sounds. *a.* Sounds originating outside the head are not located in the head when heard with one ear. Hold a loud sounding tuning fork near the ear or place it on a rubber tube, one end of which is inserted in the opening of the ear, and notice that the sound when strong may be located in the ear, but does not penetrate further. Insert the other end of the tube in the opening of the other ear and repeat. The tone if loud will appear to come from the inside of the head. Removing and replacing the fork several times will help to give definiteness to the location. *b.* Repeat the experiment, but use a fork sounding as faintly as possible (*e. g.* set in vibration by blowing smartly against it), and notice that the location when a single ear receives the sound is not so clearly in the ear, and, when both receive it, not so clearly in the head, perhaps even outside of it. Cf. also Ex. 98 *b.* These experiments may also be made with beating tones instead of a single one.

Cf. Schaefer, *op. cit.* under 94.

98. Location of the tones of tuning-forks pressed against the head. *a.* Strike a large and loud sounding tuning-fork and press its stem against the vertex. The tone will seem to come from the interior of the head chiefly from the back. While the fork is in the same position close one of the ears, not pressing it too tight; the sound will immediately seem to concentrate in the closed ear. Have an assistant manage the fork and close the ears alternately. Something of the same kind happens when a deep note is sung; close first one ear and then both and notice the passage of the tone from the throat to the ear and finally to the middle of the head. *b.* Have an assistant manage the fork and close both ears. Notice that when fork is pressed on so as to make the tone loud the intercranial location is exact, but when the pressure is relaxed and the tone is faint the location tends to be extracranial. *c.* Try setting the fork on other places than the vertex. Notice that in the occipital and parietal regions the sound appears in the opposite ear. *d.* Take a long pencil in the teeth like a bit and rest the stem of a tuning-fork vertically on it near one end and close the ear on the other side; the sound will seem to be located in the closed ear. Then gradually tilt the fork backward toward a horizontal position, keeping it in contact with the pencil till its tip is opposite the open ear. The tone will change its place from the closed to the open ear.

On *a* and *b* cf. Schaefer, *op. cit.* under 94; on *c* cf. Thompson, second article referred to under 94.